we have observed would follow when there is present at the surface (or forming the surface) a material which can induce actual chemical action between the less strongly attracted (adsorbed) of two or more radicles and an independently adsorbed substance (hydrogen).

We have used the term adsorption here in the same sense as that in which Langmuir has defined it, namely, as a phenomenon which is caused by the same forces as are operative in any other chemical action; we regard "adsorption," if it is not absolutely identical with what we have referred to as "unstable intermediate compounds," as being the immediate precursor of the latter.

The investigation of the relation between hydrogen pressure and hydrogen absorption by unsaturated compounds in presence of nickel therefore has confirmed our former views of the primary dependence of the whole process upon the relations and affinities subsisting between the catalyst and the unsaturated organic compound.

On "Light Body" Hydrophones and the Directional Properties of Microphones.

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1. *Ellipsoidal Directional Hydrophones.*

Prof. W. H. Bragg in 1916 suggested a simple form of directional hydrophone, consisting of an elongated body of rigid but light construction, in which was mounted a carbon granule microphone of the "button" type. The principle of action of this body was expected to be as follows:—If a body floats freely, wholly or partly submerged, in water through which sound waves (or other waves) are passing, it oscillates with the water and with the same amplitude as the water, provided its dimensions are small compared with the wave-length. This follows from the fact that both the mass of the body and the forces which act on it are the same as in the case of the water which it has displaced.

If, however, the mass of the body is less than that of the water which it displaces (in which case, of course, constraint must be used to keep it down), the motion of the body is greater than that of the water, provided that the constraints do not interfere with the vibratory motion, and *vice versâ*. Since the body now moves with respect to the water, the amplitude of its motion will, from hydrodynamical considerations, depend upon the shape of the body. If, for example, the body is ellipsoidal, its motion will be greatest when the greatest axis coincides with the direction of the wave. The response of the enclosed microphone will vary, therefore, with the orientation of the ellipsoid; hence the "light body" will constitute a directional hydrophone.

Prof. Lamb supplied the following data for a prolate ellipsoid. The numbers give the "inertia coefficient," or the ratio of the water-load to the mass of water displaced by the body, for different values of the ratio of the length, c, to the greatest breadth, a. The numbers are given for two orientations of the body:—(i) the "end-on" position, in which c is inclined at 0° to the direction of the propagation of the sound; (ii) the "broadside-on" position, in which c is inclined at 90° to the direction of the propagation.

Table I.

c/a.	Inertia coefficient (β).	
	End-on (β_1).	Broadside-on (β_2).
1	0·5	0·5
1·5	0·305	0·621
2·0	0·209	0·702
2·5	0·156	0·763
3·0	0·122	0·803
4·0	0·082	0·860
5·0	0·059	0·895
6·0	0·045	0·918
7·0	0·036	0·933
8·0	0·029	0·945
9·0	0·024	0·954
10·0	0·021	0·960

Let M be the mass of the body, M′ that of the fluid displaced by it, and β the inertia coefficient. Then, if the length of the sound waves is considerable compared with c or a respectively and the body is immersed and free to move,

$$\frac{\text{amplitude of body}}{\text{amplitude of sound waves}}=\frac{(1+\beta)\,\mathrm{M}'}{\mathrm{M}+\beta\mathrm{M}'}=\frac{1+\beta}{\rho+\beta}$$

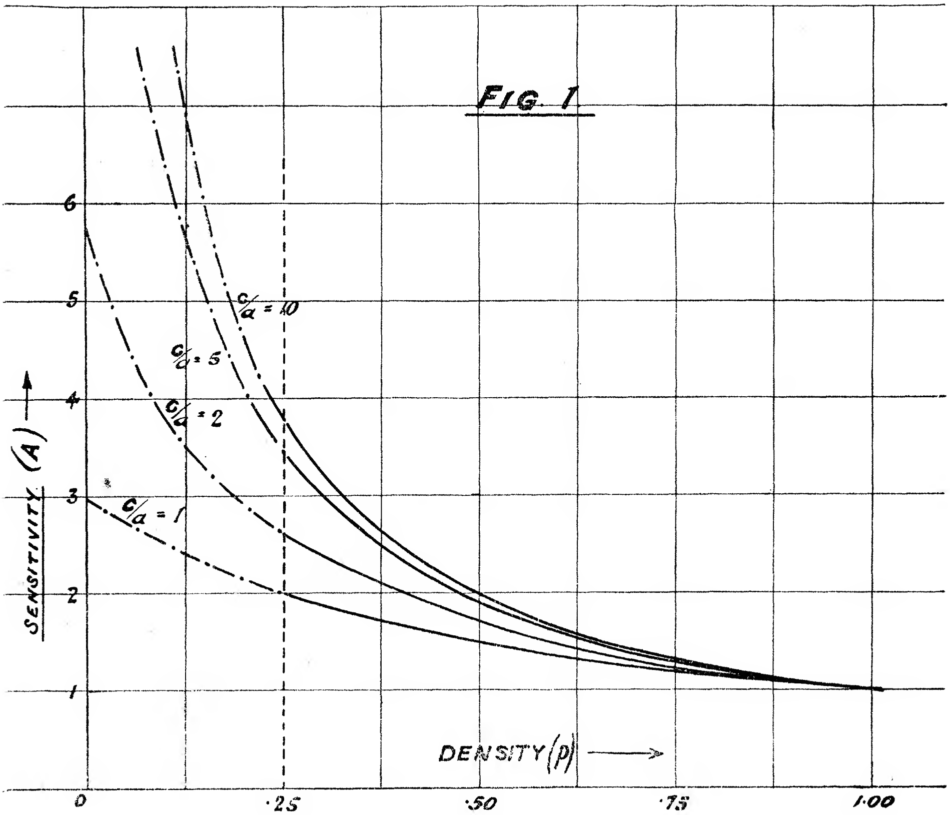
where ρ is the density of the body.

It is apparent that the relative amplitude, A_0, of the body in the end-on position is greater than its relative amplitude, A_{90}, in the broadside-on position. The ratio, A_0/A_{90}, may be termed the direction ratio, and its magnitude is a measure of the efficiency of the body considered as a direction finder.

$$A_0/A_{90} = \frac{1+\beta_1}{\rho+\beta_1} \Big/ \frac{1+\beta_2}{\rho+\beta_2}.$$

A_0 is the ratio of the maximum amplitude of the body to the amplitude of the water, and may therefore be termed the "coefficient of sensitivity." The sensitivity coefficient and direction-ratio are both of practical significance in the hydrophone; and the relations between these and the shape and density of the ellipsoidal body are shown graphically in figs. 1 and 2, for densities less than 1.

In fig. 1 the sensitivity is seen to increase as the density decreases, reaching a theoretical maximum when $\rho = 0$. The practical maximum is, however, reached when the limit of lightness consistent with rigidity is attained, since the theory assumes that the body moves without deformation of shape. This limit is, of course, indeterminate, but is probably not lower



than 0·25. Thus, though for $c/a = 10$ and $\rho = 0$, $A_0 = 46{\cdot}6$; if ρ has the minimum practical value of 0·25, $A_0 = 3{\cdot}8$.

From fig. 1 it is also seen that for any given value of ρ less than 1 the sensitivity increases with c/a, but at a rapidly diminishing rate, and in practice there is little advantage in taking a higher value for c/a than 5 or 6.

In fig. 2 is plotted the direction-ratio with density for various values of c/a. The curves have the same general character as in fig. 1, and the same general remarks apply. Though for $c/a = 10$ the directional ratio has the high theoretical maximum of about 24, it is only 2·3 when $\rho = 0{\cdot}25$.

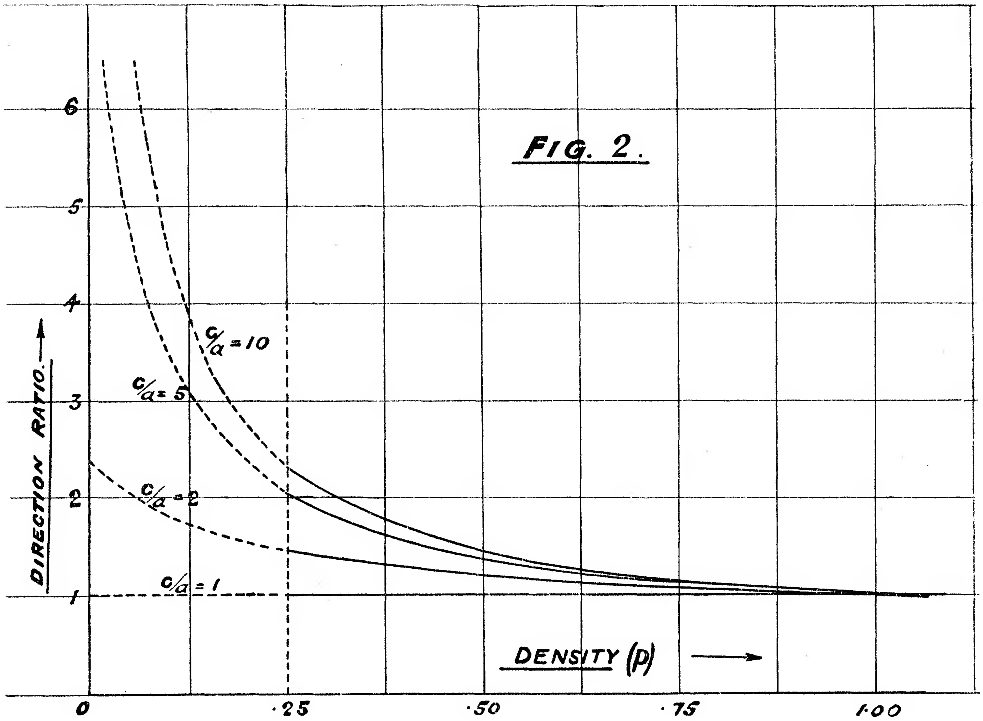
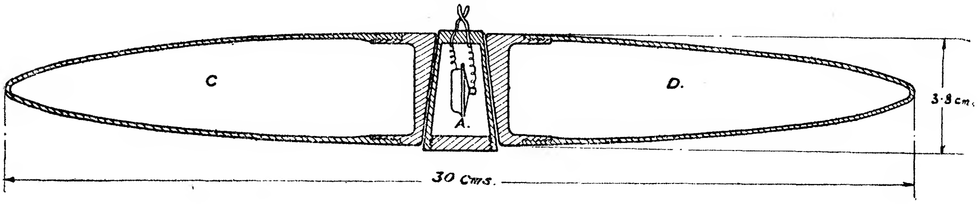


FIG. 2.

A glass ellipsoidal body was prepared by Sir E. Rutherford similar in general form to fig. 3. It consisted of two portions, fitting together with a ground-glass joint, which permitted of the insertion of a button microphone,

FIG. 3.



which was mounted with its axis parallel to the major axis of the body on a small wooden block cemented to the glass. The leads of the microphone were carried through the glass by sealed platinum wires. The external dimensions were $c = 32\cdot0$ cm., $a = 4\cdot5$ cm.; and the mean density, ρ, was 0·3. Hence $c/a = 7\cdot1$, and the direction ratio is given by

$$A_0/A_{90} = \frac{1+0\cdot035}{0\cdot3+0\cdot035} \bigg/ \frac{1+0\cdot934}{0\cdot3+0\cdot934} = 2 \text{ (nearly)}.$$

For practical test the ellipsoid was supported in a wire frame with twine ties, so that it might oscillate with a minimum of constraint, and it was immersed in a tank of water which contained also an electrical buzzer. The leads were connected in series with a battery and the primary of a telephone transformer in the customary manner. It was found that the microphone responded well to the sound waves, and on rotation about a vertical axis the body proved to have very marked directional properties. The direction ratio was, in fact, far greater than the calculated value, 2; it was estimated to be from 20 to 40.

2. *Directional Properties of Microphones.*

The discrepancy between the theoretical and the experimental direction ratio led to an examination of the button microphone. The following simple tests were made:—

(*a*) A button microphone was mounted with soft wax on a prong of a tuning fork, the other prong of which was also equally loaded. The microphone having been connected into a telephone circuit, the fork was thrown into vibration. The test was made with the axis of the microphone diaphragm, (i) parallel to the plane of vibration, (ii) at right angles to that plane. It was observed that the response was much louder in case (i) than in case (ii).

(*b*) A button microphone was mounted on an ebonite button cemented to the side of a small round-bottomed flask, the leads being passed through the cork stopper. This when immersed upright in the tank constituted a rough "light body" hydrophone which, from considerations of symmetry, should have been non-directional. It was observed, however, that as the flask was rotated about a vertical axis the response of the microphone varied very markedly, the sound heard in the telephone receivers being at a maximum when the microphone axis was parallel to the direction of the propagation and almost *nil* when the axis was at right angles to that direction.

It was thus apparent that the microphone has very pronounced directional properties, and that the glass ellipsoid owed its directional properties largely to the microphone.

An attempt was made to measure the direction-ratio, A_0/A_{90}, A_0 and A_{90}

in this case being the amplitudes of the oscillating current when the axis of the microphone was parallel and at right angles respectively to the line of propagation of the sound. The comparison between A_0 and A_{90} was made by shunting down the maximum response to equality with the minimum. The test was repeated with various specimens of microphones mounted in flasks of various sizes. It was found that the ratio varied considerably, even with the same microphone and flask, but reached values as high as 40 or 50. The method of mounting was varied, the microphone being sometimes cemented to the ebonite button by its case and sometimes screwed to the button by its diaphragm. No definite difference in the direction ratio depending upon the method of mounting was detected, the only desideratum for a high value being that the attachment should be rigid.

A number of flasks of various sizes were tested with the object of determining to what extent the sensitivity was actually affected by the mean density. One flask being retained as standard, the other flasks were fitted in turn with the same microphone, and the sensitivities of the flasks were compared directly with the standard. No very consistent results were obtained. Flasks having capacities respectively of 32 oz. (density $= 0{\cdot}10$), 12 oz. (density $= 0{\cdot}16$), and 4 oz. (density $= 0{\cdot}25$) appeared to be of about equal sensitivity, whilst a flask of 22 oz. capacity (density $= 0{\cdot}15$) was more sensitive than any. Smaller flasks of about 1 oz. or $\frac{1}{2}$ oz. capacity were, however, distinctly less sensitive, probably on account of the damping effects of the leads. The directional properties of the larger flasks seemed less certain than those of the smaller, suggesting that the larger flasks were lacking in rigidity, and it was from these experiments that the conclusion was drawn that the density cannot be reduced with advantage below about 0·25.

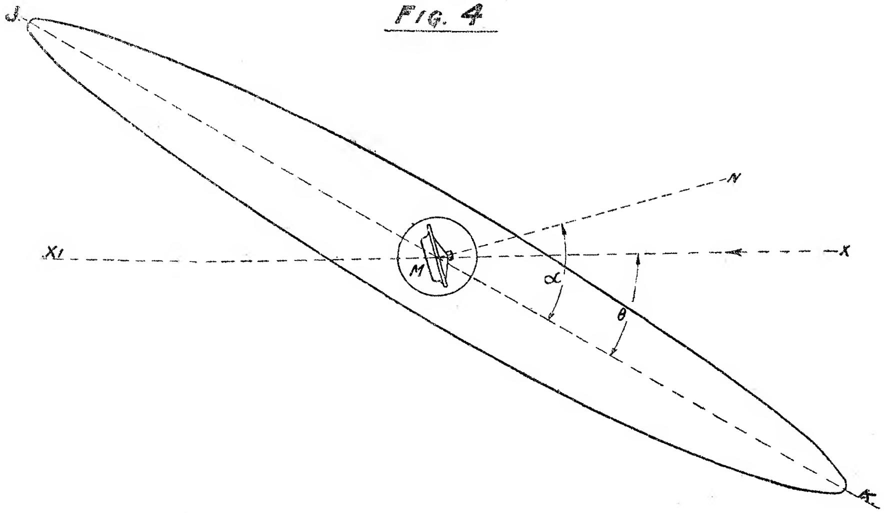
It may be mentioned that no definite indication was obtained of dissymmetry between the two maxima due to the unsymmetrical mounting of the microphone. It was necessary, however, to observe great care in maintaining the axis of the flask vertical, as the microphone proved to be very sensitive to changes in the inclination of its diaphragm.

3. *Verification of the Ellipsoidal Principle.*

Though the directional properties of the microphone prevented direct verification of the principle of the elongated light body, verification was obtained indirectly in the following manner:—A hollow ellipsoid was constructed of ebonite, 30 cm. long and 3·8 cm. broad (fig. 3). Into the central section, A, was tightly fitted a hollow conical plug, which enclosed the microphone. The end sections, C and D, could be unscrewed from A and, if desired, weighted with paraffin wax or other material. The edge of the socket in A was graduated in degrees, so that the plug carrying the microphone could be rotated through known angles. The ellipsoid was supported like the earlier glass instrument in the tank.

The microphone plug was rotated so that its axis, MN (fig. 4), made a certain angle, α, with the major axis, JK, of the ellipsoid. Then, by rotating the whole ellipsoid, the position was found for which the response of the microphone was a maximum and the angle, θ, made by JK with the direction, XX_1, of propagation of the sound was determined. In practice the body was rotated in either direction in turn until the two positions of the minimum response were reached, and the position of the maximum was then assumed to lie midway between these, this plan being adopted owing to the far greater accuracy with which the minima could be determined than the maxima. The angle θ was determined in this way for various values of α.

FIG. 4



The mean density of the ellipsoid as first employed was found to be 0·42. A second set of readings was made at a mean density of 1·0, the body being suitably loaded. A further series of readings at a still higher density was abandoned, owing to the low sensitivity of the instrument and the indefiniteness of the maxima. The readings are tabulated in Table II.

It will be observed that the readings were indefinite for $\rho = 1$, $\alpha = 60^\circ$, whilst for $\rho = 1$, $\alpha = 75^\circ$ the minima were so vague that the readings are omitted. It is probable that the method of loading up the body affected its rigidity, leading to disturbing vibrations within the body itself. When the load was further increased these disturbances became so serious as to make observations impracticable.

Table II.

α.	θ (mean value).		Tan α/tan θ.		A_0/A_{90} (from Lamb's figures).	
	$\rho = 0{\cdot}42$.	$\rho = 1{\cdot}00$.	$\rho = 0{\cdot}42$.	$\rho = 1{\cdot}00$.	$\rho = 0{\cdot}42$.	$\rho = 1{\cdot}00$.
°	°	°				
0	0	0	—	—	1·60	1
30	−18	−30	(1·8)	1		
45	−33	−45	1·54	1		
60	−48	−55 −70	1·63	—		
75	−68	?	1·50	?		
90	−90	−90	—	—		
		Mean =	1·56	1·0		

The observations indicate that when $\rho = 1$ the directional properties of the instrument reside entirely in the microphone, as theory would indicate. When $\rho = 0{\cdot}42$, though the influence of the microphone still predominates, the readings show clearly the effect of the ellipsoidal form.

The data given by Prof. Lamb may be tested as follows:—As before, let A_0 and A_{90} be the respective amplitudes of the ellipsoid (in terms of the amplitude of the water taken as unity) for the positions $\theta = 0°$ and $\theta = 90°$. Let JK be rotated through any angle θ. Then the amplitude of the sound waves may be resolved into rectangular components acting along JK and at right angles to JK respectively; the corresponding component amplitudes of the ellipsoid will be $A_0 \cos\theta$ and $A_{90} \sin\theta$.

Again, resolving each of these components in directions parallel to and at right angles to the axis of the microphone, the amplitude A_m in the former direction is given by

$$A_m = A_0 \cos\theta \cos\alpha + A_{90} \sin\theta \sin\alpha.$$

If now we assume that the microphone is practically insensitive except to vibrations parallel to its axis, MN, then the response of the microphone will be proportional to A_m. Hence the condition that the response shall be a maximum is that $\dfrac{dA_m}{d\theta} = 0$, *i.e.*, that $\dfrac{A_0}{A_{90}} = \dfrac{\tan\alpha}{\tan\theta}$.

Thus the ratio A_0/A_{90} for the ellipsoid should be calculable from the experimental values of α and θ. The values of tan $\alpha/\tan\theta$ are given in Table II.

From Lamb's data, if $\rho = 0{\cdot}42$ and $c/a = 30/3{\cdot}8 = 7{\cdot}9$,

$$A_0/A_{90} = \frac{1 + 0{\cdot}030}{0{\cdot}42 + 0{\cdot}030} \Bigg/ \frac{1 + 0{\cdot}944}{0{\cdot}42 + 0{\cdot}944} = 1{\cdot}6.$$

This value is in very fair agreement with the value of $\tan\alpha/\tan\theta$, except in the case where $\alpha = 30°$, when the angle θ to be determined acoustically is small and is liable to a comparatively big proportionate error in the setting of the apparatus. If $\rho = 1{\cdot}00$, then $A_0/A_{90}=1$ for all values of c/a. This is also in agreement with the experimental results. It was observed that as the ellipsoid was loaded up the response of the microphone became feebler, as theory would predict. No quantitative data, however, were obtained.

4. "*Light Body*" *Directional Hydrophones.*

The salient facts in regard to the production of a practical "light body" directional hydrophone may be summarised as follows:—

(i) Assuming the minimum density consistent with rigidity to be 0·25, the sensitivity coefficient may vary with the elongation from 2·0 for $c/a = 1$ to 3·8 for $c/a = 10$. The variation is less for higher densities.

(ii) The maximum direction ratio due to elongation is about 2·3 under practical conditions; this is negligible compared with the direction ratio obtainable from a well mounted microphone.

Hence it appears that little advantage is gained from adhering to the ellipsoidal form, whilst a sphere has the advantages of greater compactness and greater rigidity.

Probably from the acoustic point of view no more suitable material than glass could be employed were it not so fragile. Ebonite has, however, been found to give good results, the shell being turned as two hemispheres, which are carefully fitted and cemented together. Prof. A. L. Hughes employed with equally good results spheres of paraffin wax, cast round a light central brass box containing the microphone. In the case of the ebonite instruments various sizes were tested; the experiments led to the conclusion that no increase of efficiency was obtainable by increasing the diameter of the sphere beyond about 2 inches. Elongated bodies containing rigidly mounted microphones have been employed by various experimenters with some success as towed hydrophones.

The "light body" hydrophone is inferior in sensitivity to other types, and in practice would need slight amplification. But owing to the well-known fact that a carbon granule microphone is never entirely free from crepitation, which is amplified together with the vibrations to be transmitted, the use of an amplifier with such a microphone is open to objection. A small ebonite spherical hydrophone 1 inch in diameter, however, proved invaluable as an exploring instrument in certain investigations made by the writers and described elsewhere.